(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) Publication number: **0 467 036 A2**

(12) **EUROPEAN PATENT APPLICATION**

(21) Application number: **91107878.0**

(51) Int. Cl.5: **G01S 13/74**

(22) Date of filing: **15.05.91**

(30) Priority: **15.06.90 US 538546**

(43) Date of publication of application:
22.01.92 Bulletin 92/04

(84) Designated Contracting States:
AT BE CH DE DK ES FR GB GR IT LI LU NL SE

(71) Applicant: **SAVI TECHNOLOGY, INC.**
260 Sheridan Avenue, Suite 200
Palo Alto, California 94306(US)

(72) Inventor: **Reis, Robert S.**
167 Rinconada Avenue
Palo Alto, California 94301(US)
Inventor: **Stevens, Richard K.**
21070 Rainbow Place
Cupertino, California 95014(US)

(74) Representative: **Liesegang, Roland, Dr.-Ing.**
FORRESTER & BOEHMERT
Widenmayerstrasse 4
W-8000 München 22(DE)

(54) **Method and apparatus for radio identification and tracking.**

(57) Items are identified and tracked by attaching radio transceiver tags to the items and sending signals between the tags and one or more interrogation subsystems. The tags are normally in low-power standby mode unless signalled by an interrogator. The interrogator broadcasts a signal to all of the tags within reception range, and the tags respond after pseudo-random delays. When the interrogator has identified a tag, it signals that fact back to the tag and the tag returns to standby mode. The tags that were not identified by the interrogator retransmit their identification signals, and the process continues until all tags within range of the interrogator have been identified.

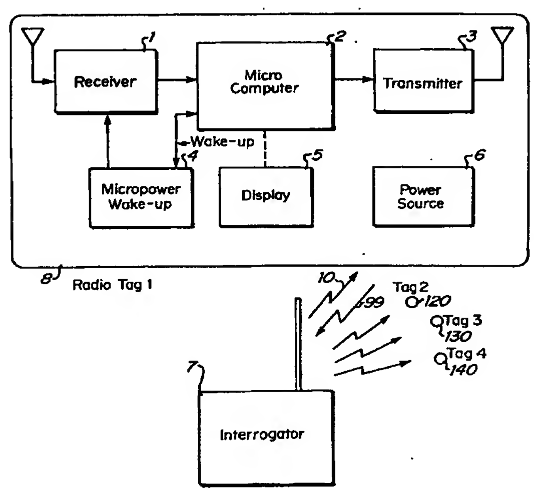

Figure 1

EP 0 467 036 A2

This invention relates generally to a method and apparatus for tracking and identifying physical objects, and more particularly to radio frequency identification and tracking systems using product tags having built-in radio frequency transceivers.

A number of systems are known to exist that aid in the identification and tracking of physical objects in various environments. For instance, (1) Optical barcode readers are typically used in supermarkets to track product movement. (2) Optical character recognition systems are used in some department stores for the same purpose. (3) Magnetic stripe readers are commonly used to identify bank cards in automated teller machines. (4) Sophisticated security systems make use of voice recognition to identify humans. (5) Radio Frequency Identification ("RF/ID") offers another approach to automatic identification and tracking.

Historically, RF/ID systems have used one of two radio communication techniques. One type of system has used passive RF reflectors, and the other type has used magnetic couplers.

In the passive systems, RF-reflective "tags" are affixed to the products to be identified or tracked. When the products are positioned within sufficient range of an RF source, the tags are energized by the incident RF energy. The illuminated tags reflect a portion of the RF back to a receiver, modifying some aspect of the RF in the process. The product is identified by the manner in which the incident RF energy is modified upon reflection.

The passive reflector tags of the prior art have several inherent limitations. The signal-to-noise ratio of the resultant identification signal is dependent upon the incident power level of the illuminating RF source, the geometry of the reflector and the efficiency of the modulation and reflection process. It is therefore common for the identification signal to be substantially weaker (e.g., 100 dB weaker) than the illuminating signal. Thus, very strong illuminating signals are required for the process to work even over limited ranges. Accordingly, passive reflector systems require directed illumination rather than omnidirectional illumination to achieve reasonable ranges. Omnidirectional illumination is generally preferred because it does not require prior knowledge of the location of the tag with respect to the illuminating source.

Additionally, the communication process of a passive reflector is fundamentally one-way. The purpose of the illuminator is not to communicate any information to the tag, but only to provide a source of activating energy. There is no method for "handshaking" between the product tag and the central system to verify that the proper identification has been made.

The third disadvantage of passive reflector tags of the prior art is their inability to dynamically store data. The interrogator of such a system has no means to dynamically write data into the tag for later re-transmission by the tag. Effectively, the tag becomes a mere static identifier for the attached item. Such tags lack the capability to change characteristics appropriate to the dynamic environment of the tags.

In systems using magnetic coupling, radio tags are energized by movement through a magnetic field, and the energized tags transmit magnetically-coupled energy back to the interrogator unit. Am alternating field generated by an induction coil may be employed to generate the requisite energizing magnetic field for this system. This communication is typically transmitted at very low frequencies ("VLF").

Magnetically-coupled radio tags are inherently restricted to close-range communications. This is due to the coupling inefficiency of small loop antennas (necessitated by the tag size) at VLF frequencies.

Summary of the Invention

To overcome the limitations of the prior art RF/ID systems, the method and apparatus of the present invention includes radio frequency reception and transmission capability at both the tag end and at the interrogation end of the system. Communication via active optical, infrared, UV, magnetic and acoustic media could also be used in accordance with the present invention. The method and apparatus of the present invention uses handshaking to verify the receipt of correct information from each individually tagged item. In accordance with the present invention, spatial, polarization, time and frequency diversity methods may be employed to overcome the limitations of multipath or multiple-device interference in the radio tag environment. The method and apparatus of the present invention use a intentional cellular communication range restriction to assist in the locating of said tags. In accordance with the present invention a MESFET front end is coupled to a super-regenerative receiver. This electronic circuit configuration substantially reduces interference normally associated with super-regenerative receivers and permits the use of inexpensive super-regenerative receiver technology in the congested environment of closely associated radio tags. In accordance with the present invention some characteristic of the intentional radiation (e.g., phase, time-of-arrival, angle-of-arrival) is used to determine the location of the tag relative to the interrogator within a cell. The method and apparatus of the present invention also increases the robustness of communications by handling situations in which signals from individual tags are

time-coincident at the interrogation end.

Description of the Drawings

Figure 1 is a block diagram of the radio tag subsystem of apparatus in accordance with the present invention.

Figure 2 shows the use of multiple interrogators in a cellular tag tracking system, in accordance with the present invention.

Figure 3 is a block diagram of the MESFET front end of the tag receiver shown in Figure 1.

Figure 4 is a schematic diagram of the micropower wake-up circuit shown in Figure 1.

Figure 5 is a block diagram of interrogator subsystem of apparatus in accordance with the present invention.

Figure 6 is a flowchart of the Batch Collection Protocol as implemented in the interrogator subsystem of Figure 5.

Figure 7 is a flowchart of the Batch Collection Protocol as implemented in the radio tag subsystem of Figure 1.

Figure 8 is a timing diagram showing the operation of the random delay process.

Figure 9 is description of the preferred data format for communications between the tag and interrogation subsystems in accordance with the present invention.

Figure 10 is a functional block diagram of one embodiment of a linear recursive sequence generator in accordance with the present invention.

Description of the Preferred Embodiment

Referring now to Figure 1, a block diagram for apparatus in accordance with the present invention is shown. Two major types of subsystems comprise the apparatus: the tag transceiver subsystems 8, 120, 130, 140 and the interrogator subsystem 7. The tag transceiver subsystem 8 is comprised of a receiver 1 to capture and demodulate the signal 10 from the interrogator 7 and a transmitter 3 to modulate and emit the signal 99 back to the interrogator 7. Further comprising this tag are a microcomputer 2, which processes data from the received signal, applies batch collection protocol to verify communications and controls the transmitter 3; a power source 6; an optional display 5; and a micropower wake-up circuit 4. The wake-up circuit 4 keeps the tag in a very low power state until a predefined wake-up signal is heard. The display 5 can be used to provide status information about the identification or tracking process, or to display other messages to personnel viewing the RF tag 1.

Referring now to Figure 2, multiple interrogators may be positioned and networked to create a cellular reception environment. Interrogators 10, 101, 102, 103 located in each of the cells 15, 12, 13, 14 communicate with a computer 11 via a network 110 of conventional design (wired-line, optical fiber, radio link, etc.), and also with all of the radio tags located within the communication cell of that interrogator. The cells 12, 13, 14, 15 correspond with the communication radius of the interrogators 101, 102, 103, 10, respectively. An array of these interrogator communication cells placed strategically around a facility provides the necessary communications structure to communicate with all of the tags located in the facility. As the identifying signal from each tag is heard, the corresponding interrogator communicates the identification code to the monitoring computer, thereby identifying not only the tag, but the approximate location of the tag as well. If only identification information, and not location information, is required, a single cell system without a computer 11 or network 110 may be used, in accordance with the present invention.

Referring now to Figure 1 and Figure 3, any type of receiver and transmitter can be used in accordance with the invention (e.g., infrared, acoustic, RF, optical, magnetic). In the preferred embodiment RF at VHF is used. A receiver module 1 comprising a conventional superregenerative receiver 22 coupled to a MESFET front-end 21 and a conventional on/off keyed AM transmitter 3 are used. Also, any type of microcomputer 2 can be used as long as the speed of the processor is sufficient to process the data and implement the necessary batch collection protocol. In the preferred embodiment, an 8-bit microcontroller is employed.

In the preferred embodiment, the tag receiver 1 is a modified superregenerative receiver. The modification is shown in Figure 3 and involves the addition of an FET (field-effect transistor) front end 21 to a superregenerative receiver of the standard variety 22. Without the use of the FET front-end, the superregenerative receiver would emit an RF signal (noise) back into the environment via the directly-connected antenna and would interfere with the reception capabilities of other close-proximity tags. FET circuits characteristically have extremely high reverse signal isolation, so the use of a FET front end substantially reduces leakage of RF and quench energy from the receiver and at the same time increases the sensitivity of the receiver. As a result, this design in accordance with the present invention permits the use of an inexpensive receiver design, such as a superregenerative circuit, in the demanding network environment of radio tag communications.

Referring now to Figures 1 and 4, to increase the service life of the power source 6, which is typically a small battery, the receiver module 1 in

the tag subsystem 8 normally remains in a quiescent low-power state for all but a small fraction of the time. During the small time intervals that the receiver module 1 in the tag subsystem 8 is activated, the energizing power from the wake-up module 4 allows detection of the wakeup signal arriving from the interrogator 7. If no such signal is detected, the tag receiver subsystem 8 continues its sleep/wake cycle by returning to the low-power state. If, however, RF energy from the interrogator 7 is detected, the tag subsystem 8 changes to full power mode to prepare for communication with the interrogator 7.

Referring now to Figure 1 and Figure 4, in the preferred embodiment, the micropower wake-up circuit 4 uses an extremely low-drain astable oscillator to strobe energy to the receiver. The design of the wake-up circuit 4 is based on a programmable opamp 30 used in an extremely-low power mode. In the preferred embodiment, a 50 megohm current-set resistor 31 is employed. High-speed switching diodes 32, 33 are configured in a quasi anti-parallel mode to provide a highly assymetric (low duty cycle) wakeup waveform. Resistors 37 and 38 are used to bias op-amp 30 at a level one half of the system voltage level. Resistor 34 and capacitor 35 are selected to provide an oscillator which is active for a short period (approximately 1 millisecond in the preferred embodiment) and inactive for a long period (approximately 1 second in the preferred embodiment). The oscillator signal then strobes a pair of high source-current logic gates 36, 37, which can then cleanly power the rest of the receiver circuit.

The resulting power strobe circuit of Figure 4 has the ability to source the current (10 milliamps) necessary to power the receiver circuit, yet itself draws only 2 microamps on average during the 99 msec. that the receiver is not active.

Referring now to Figure 5, the interrogator apparatus consists of a receiver 50, a microcomputer 51, a transmitter 52, memory 53, and optionally a display 54, optional keypad 55, modem 56 and cable interface 57. All of these components are conventional in design except possibly for the receiver 50. The receiver 50 may be either of conventional superhetrodyne design or may be an FET-modified superregenerative receiver such as described in connection with Figure 3.

Various techniques may be employed in accordance with the invention to improve the robustness of the communication against signal multipath and other interference. Example techniques include antenna diversity, frequency diversity, polarization diversity, and time diversity. In the preferred embodiment, a combination of antennas 59, 60, 61 employing both polarization diversity and spatial diversity are used in the front end module 58 to the receiver 50.

A second mode of signal enhancement that may be employed in the interrogator apparatus is parameter enhancement. For instance, effective transmission power may be enhanced through the use of repeater apparatus, and other apparatus may be used to determine the direction and range from a repeater to a tag. To implement the repeater enhancement, certain relay units rebroadcast a tag signal to a more distant interrogator unit that has a particular association with that particular tag. Such a system increases the effective range between tags and their associated interrogators. The ranging and direction-finding enhancements may be implemented by employing acoustic transducers in one path of the two-way link between the tag and the interrogator. Acoustic waves propogate much more slowly than do electromagnetic waves and therefore can be used for more accurate short-range location using conventional echo-location techniques. In addition, multiple acoustic beams may be used to provide direction measurement using conventional triangulation techniques.

Referring now to Figures 6, 7 and 8, in accordance with the invention, a batch collection protocol or method is employed to handle situations in which multiple tag subsystems respond simultaneously to the presence of RF energy from an interrogation subsystem 7.

Many common applications of the present invention would not require constant interrogation of all tags within radio range of the interrogator 7. In such applications, all tags normally remain in low-power standby mode, as previously discussed. When interrogation is desired, a interrogation "wake-up" signal is transmitted by the interrogator 62. In the preferred embodiment this signal is a VHF radio signal modulated at 62 KHz. This signal must be sent for a period equal to or greater than the micro-power scan period, or 1000 milliseconds in the preferred embodiment. When the wake-up signal is received by the tag 1, the reset pin of the microcomputer 2 is activated. The reset wakes up the microcomputer from its low-power state and initiates the wake-up routine. The routine is called "Listen for Hello" 72.

After a delay sufficient for all tags to get to state 72, a "Hello" command is sent by the interrogator. The "Hello" is a signal that instructs all tags that have been awakened to begin their response protocol. Referring now to Figure 9, the preferred format of the "Hello" signal, and all other data exhanges, is a pulse-width modulated code which is configured with 80 microsecond pulses and 40 or 80 microsecond spaces, corresponding to a data information bandwidth not exceeding 25 kHz. However, other data exchange systems could also be used in accordance with the present inven-

tion.

The reception of the "Hello" signal begins the send/acknowledge loop shown as steps 73, 74, 75 in Figure 7. First, a delay is computed 73. This delay needs to be as random as possible for the collision avoidance technique to work efficiently. In the preferred embodiment, a linear recursive sequence generator 90 seeded by the tag identification address is used to generate these delays, as shown in Figure 10.

The tag responds at this delay time with its identification address 74 and then waits for acknowledgement 75. During this fixed listen cycle 64, the interrogator places all of the identification codes heard during the cycle into a dynamic database 65. At the end of the listen cycle (assuming at least one ID code was heard) it transmits the list of received ID codes back to the tags 66. If no new tag signals were received 67, 68, 69 then the process ends.

The tags collectively wait for acknowledgement that they were heard 75. If the unique ID code of a tag is properly received in the interrogator acknowledge cycle 66, 75 then this tag can return to stand by mode 76. If it is not acknowledged, then the tag tries again by sending its ID code back to the interrogator, albeit with a different delay period 72, 73, 74, 75.

Since the transmission time of the identification packet is small relative to the listen period (see Figure 7), the probability of tag responses colliding on top of one another is small and gets even less probable as the process continues. The probability of collision of each cycle is determined by the duty cycle, the listen period, the number of tags heard and the degree of randomness of the transmit delay for each transmission.

For the preferred embodiment, a probability of collision of one per one hundred tag units is defined.

Typically, with a well balanced collision protocol, the collision iteration process occurs at approximately a square-law rate.

The timing of this process is demonstrated graphically in Figure 8. The interrogator wakes-up all tags in the wake-up state 81, begins the listen cycle 82 by sending out a 'hello' command, acknowledges tags 83 and repeats the process 84, 85, 86 until all collisions have been resolved.

The networking scheme described above can be further enhanced by the use of A) targeted wake-up [a special hello code is sent followed by an address code] which wakes up only that specific tag; B) messaging [the tag appends a message into its address in the listen cycle] and C) reverse messaging [the interrogator adds a message to a specific tag's acknowledgement].

In accordance with the present invention, the collision avoidance method could employ randomization based on any of several communication parameters. In the preferred embodiment, response delay is used. However, the method could employ frequency, phase, amplitude or spatial variation as well.

Therefore, an identification and tracking system uses two-way communications between a central interrogator and individual radio transceiver tags to identify tagged items within the reception and transmission range of the interrogator.

Claims

1. A method for identifying and tracking items, characterized in that a transceiver tag is associated to each of the items to be tracked; an interrogation signal is transmitted to the transceiver tags; identification signals are selectively transmitted from the transceiver tags responsive to reception of the interrogation signal by the transceiver tags; the identification signals are received; a verification signal is transmitted responsive to receipt of the identification signals; and additional identification signals are transmitted from the transceiver tags responsive to receipt of the verification signal.

2. The method according to claim 1, characterized in that the interrogation signal is transmitted by a central interrogation transceiver subsystem.

3. The method according to claims 1 or 2, characterized in that all tags within receiving range of the interrogation signal transmit identification signals.

4. The method according to claims 1, 2 or 3, characterized in that the step of selectively transmitting identification signals further comprises the step of each tag delaying initiation of transmission of the identification signal a particular amount of time after receipt of the interrogation signal.

5. The method as in claims 1, 2, 3 or 4, characterized in that the particular amount of time is determined in a psuedo-random manner.

6. Apparatus for identifying and tracking items, characterized in that a plurality of transceiver tags (8, 120, 130, 140) are affixed to the items; an interrogation transceiver subsystem (7) communicates with the transceiver tags, the interrogation transceiver subsystem having the capability to initiate the transmission of an

identification signal from selected tags and identify the tags sending identification signals.

7. Apparatus as in claim 6, characterized in that the transceiver tags (8, 120, 130, 140) remain in a low-power standby mode until activated by a wake-up signal (81) from the interrogation transceiver subsystem (7).

8. Apparatus as in claims 6 or 7, characterized in that the initiation of identification signals is responsive to receipt by transceiver tags (8, 120, 130, 140) of an initiation signal from the interrogation transceiver subsystem (7).

9. Apparatus as in claims 6, 7 or 8, characterized in that the identification signal from each tag (8, 120, 130, 140) is unique.

10. Apparatus as in claims 6, 7, 8 or 9, characterized in that a power strobe circuit periodically provides a signal to a microprocessor in each transceiver tag to cause low-power standby operation.

11. Apparatus as in claims 7, 8, 9 or 10, characterized in that protocol signal control means prevent communication loss between the interrogation transceiver subsystem (7) and the transceiver tags (8, 120, 130, 140) due to simultaneous identification transmissions from two or more transceiver tags (8, 120, 130, 140).

12. Apparatus as in claims 6, 7, 8, 9, 10 or 11, characterized in that protocol means iteratively acknowledges receipt of identification information from particular tags and requests remaining tags to resend identification transmissions until all responding tags have been identified.

13. Apparatus as in claim 12, characterized in that the protocol means further comprises means in the transceiver tags (8, 120, 130, 140) for delaying identification transmissions by each remaining tag for a particular period of time after the protocol means signal that retransmission will be required.

14. Apparatus as in claim 13, characterized in that the particular period of time is different for each remaining tag and is determined in a pseudo-random manner.

15. Apparatus as in claims 6, 7, 8, 9, 10, 11, 12, 13 or 14 further characterized in that the apparatus comprises means for determining the location of transceiver tags (8, 120, 130, 140).

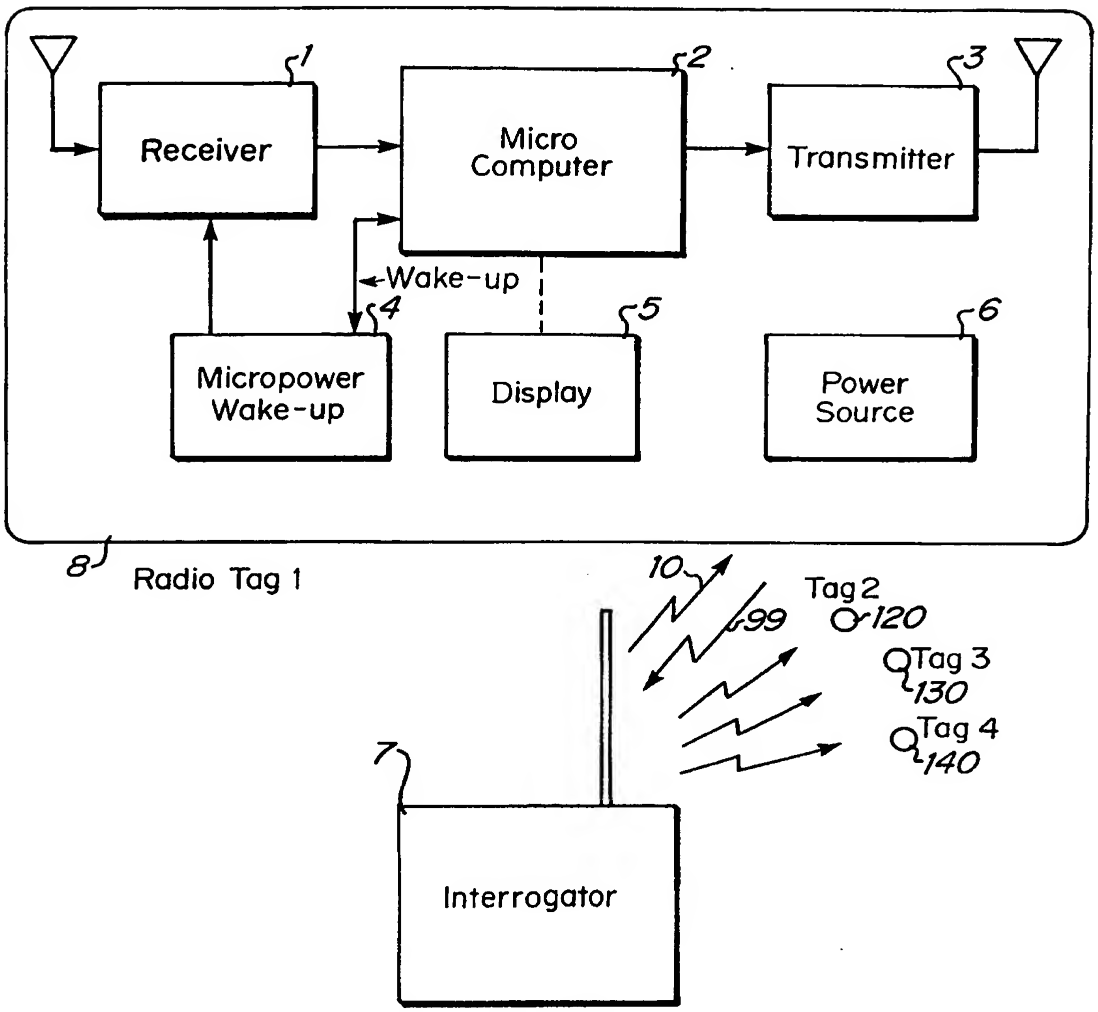
Receiver
1
Micro Computer
2
Transmitter
3
Wake-up
4
5
6
Micropower Wake-up
Display
Power Source
8
Radio Tag 1
10
99
Tag 2
120
Tag 3
130
Tag 4
140
7
Interrogator

Figure 1

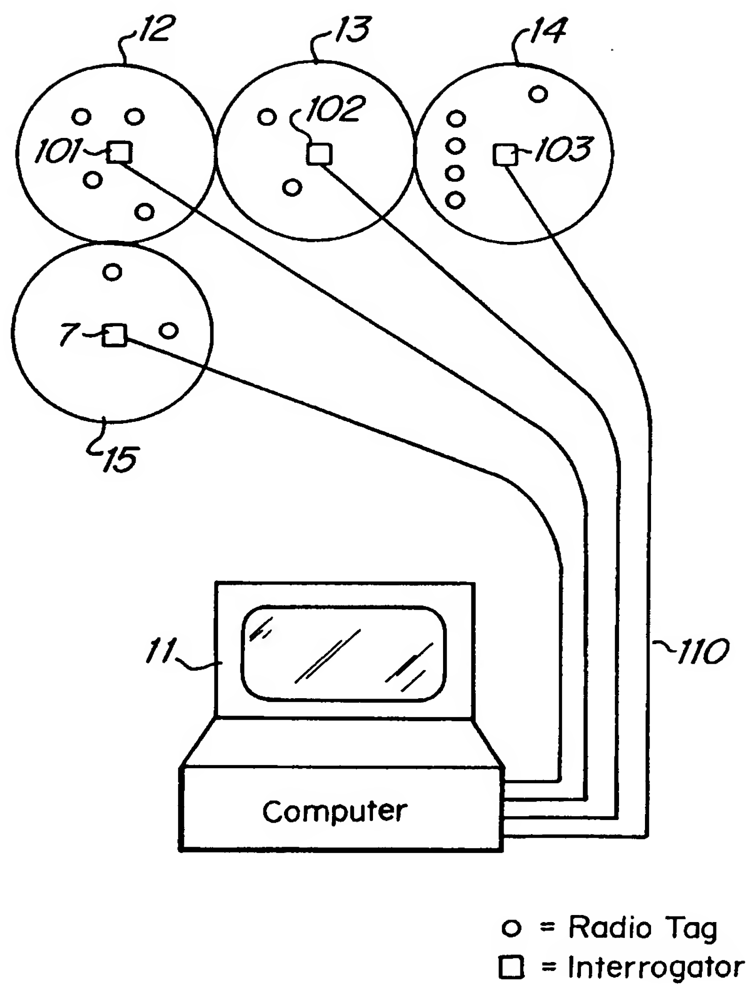
12
13
14
101
102
103
7
15
11
110
Computer
o = Radio Tag
□ = Interrogator

Figure 2

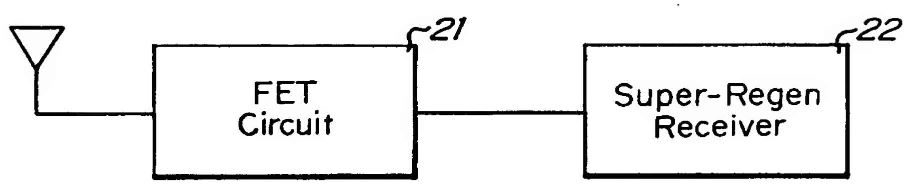

Figure 3

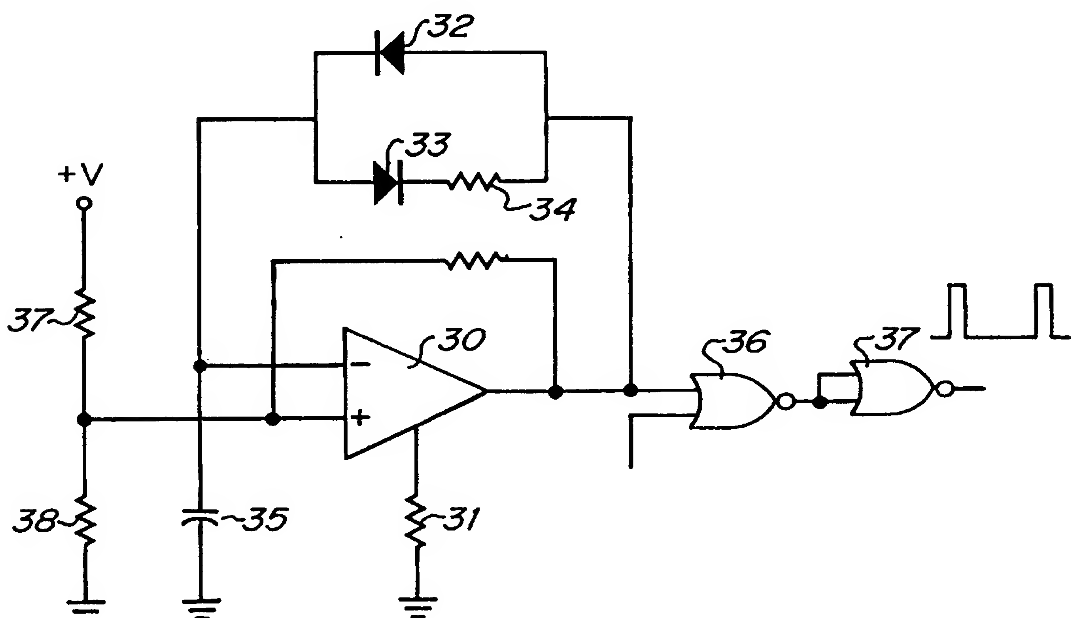

Figure 4

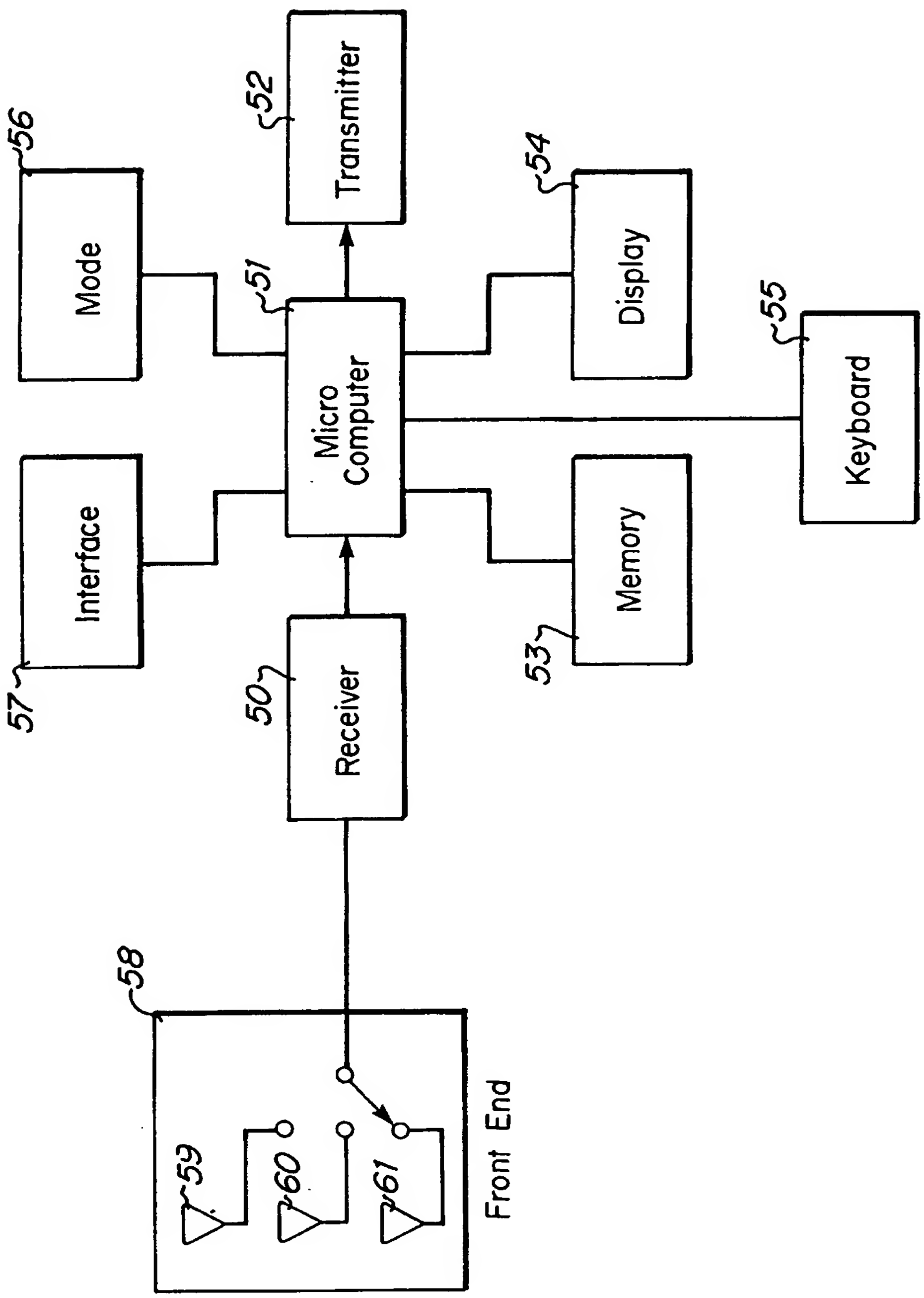
Mode
56
Transmitter
52
Micro Computer
51
Display
54
Interface
57
Receiver
50
Memory
53
Keyboard
55
Front End
58
59
60
61

Figure 5

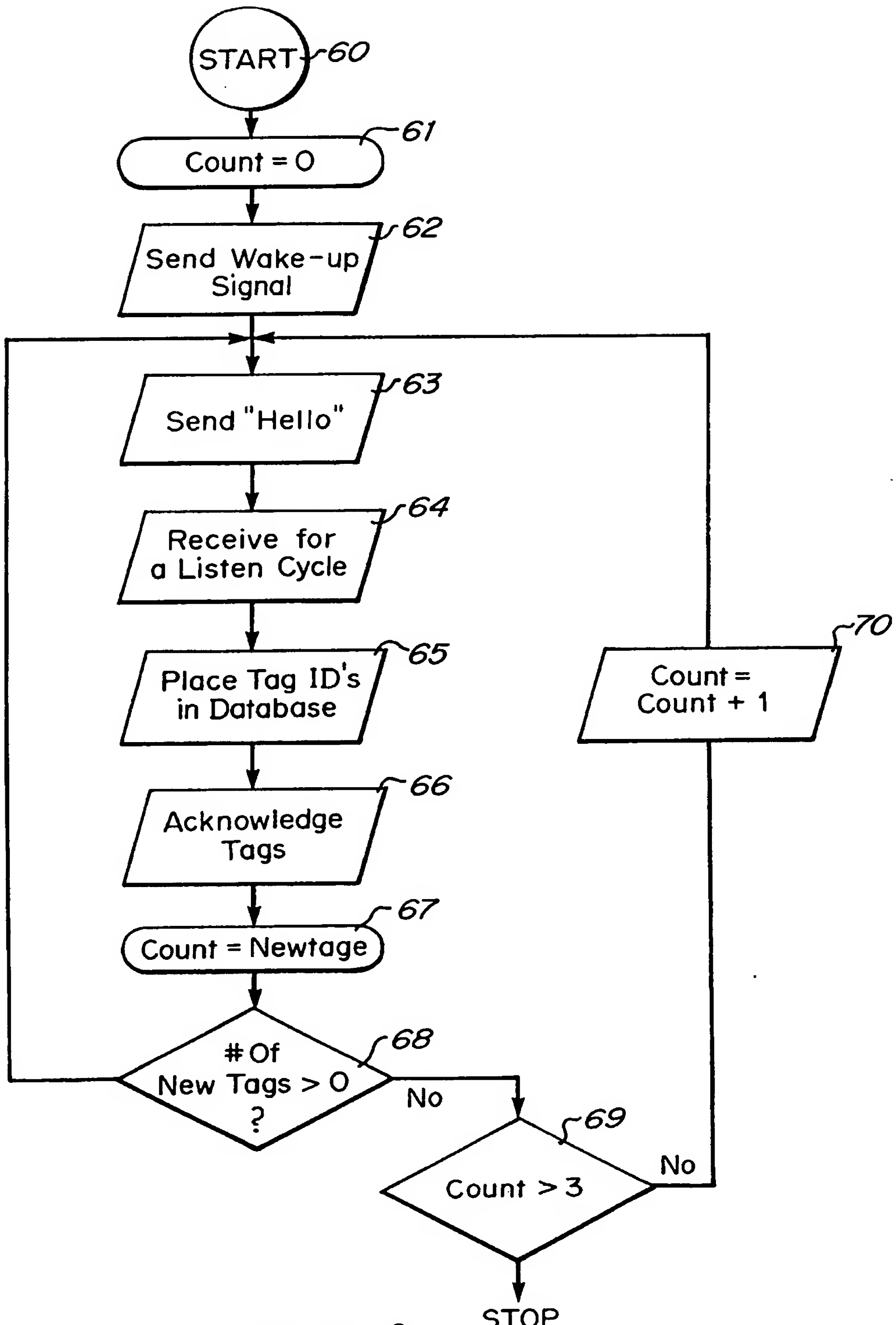
START
60
Count = 0
61
Send Wake-up Signal
62
Send "Hello"
63
Receive for a Listen Cycle
64
Place Tag ID's in Database
65
Acknowledge Tags
66
Count = Newtage
67
Of New Tags > 0 ?
68
No
Count > 3
69
No
Count = Count + 1
70
STOP

Figure 6

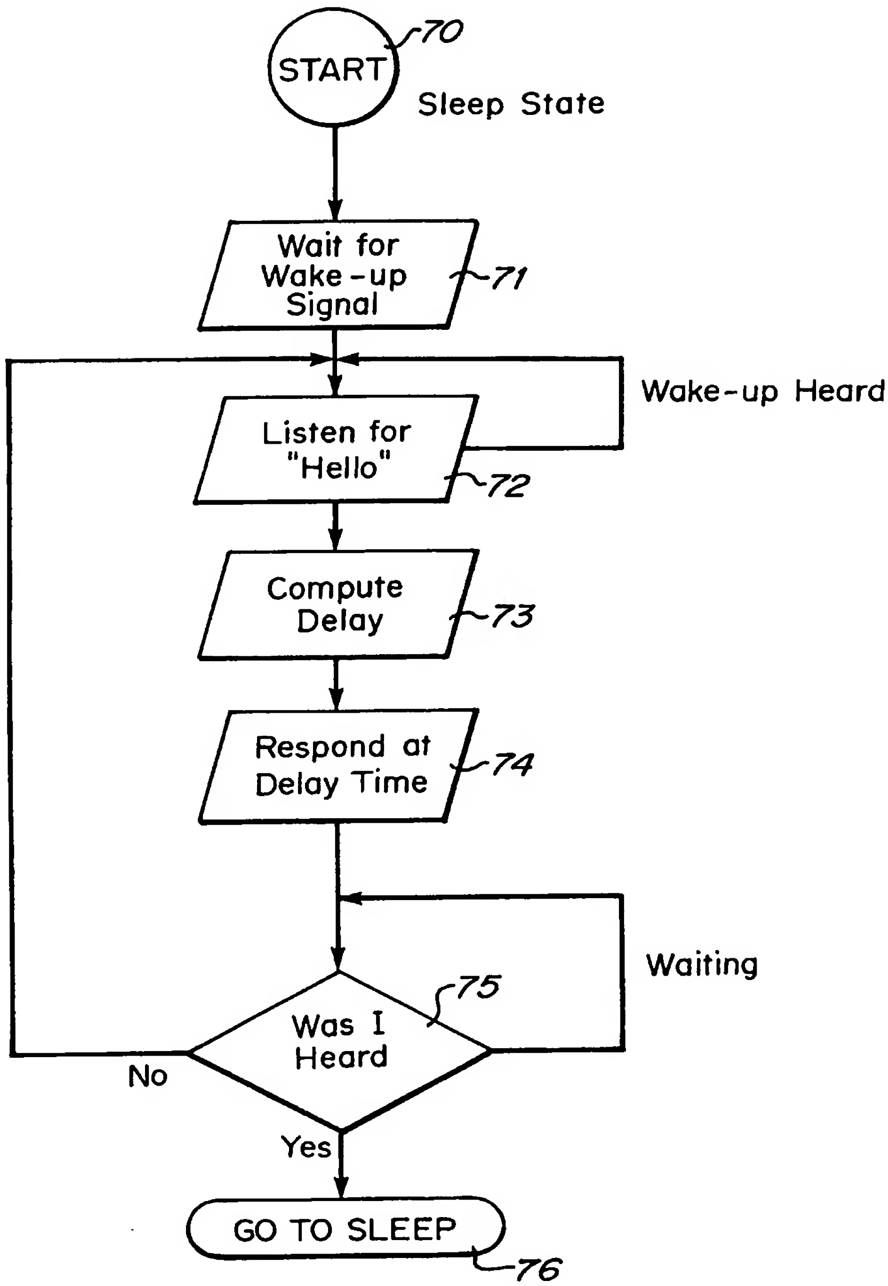
START
70
Sleep State
Wait for Wake-up Signal
71
Wake-up Heard
Listen for "Hello"
72
Compute Delay
73
Respond at Delay Time
74
Waiting
Was I Heard
75
No
Yes
GO TO SLEEP
76

Figure 7

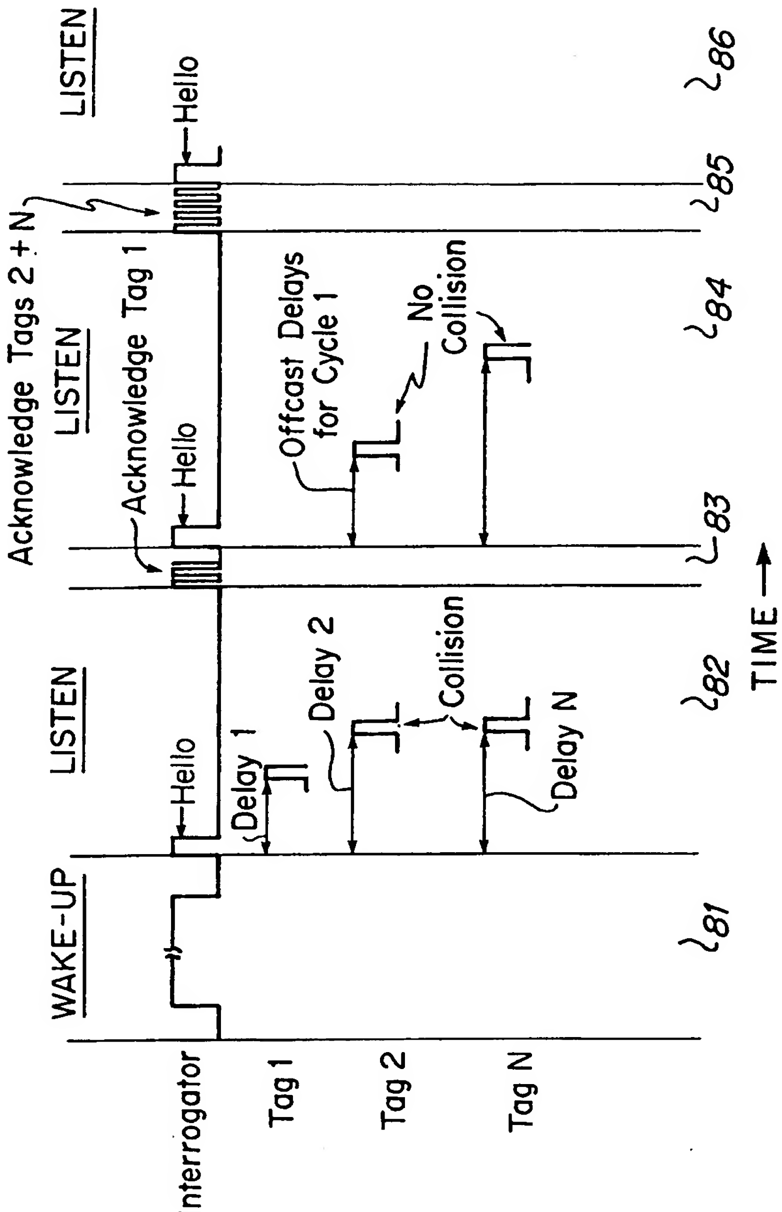
WAKE-UP
LISTEN
LISTEN
LISTEN
Acknowledge Tags 2 + N
Acknowledge Tag 1
Hello
Hello
Hello
Interrogator
Tag 1
Tag 2
Tag N
Delay 1
Delay 2
Delay N
Collision
Offcast Delays
for Cycle 1
No
Collision
81
82
83
84
85
86
TIME

Figure 8

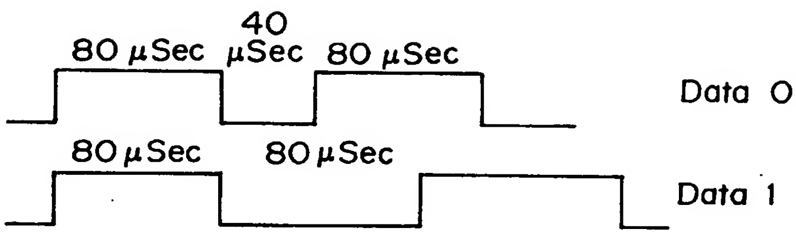

Figure 9

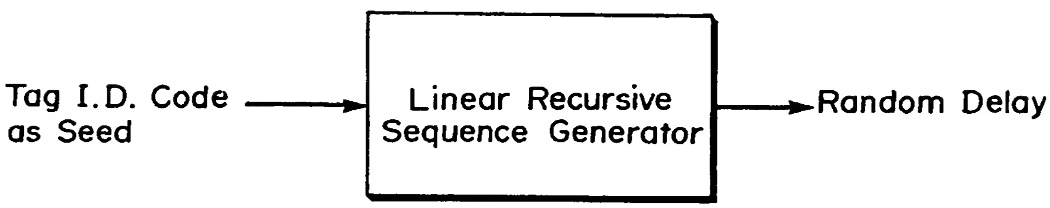

Figure 10